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PARTON LUMINOSITIES AND SMALL-X PHYSICS[*][†]

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Abstract

Sensitivity of Parton luminosity functions at small x and SSC energies to assumptions about input parton distribution functions at current energies is studied. QCD-evolved distribution functions using a variety of input distributions and parameters are calculated to generate the relevant luminosity functions. Most inputs based on the commonly assumed $1/x$ behavior at small x yield comparable results for a variety of choice of top quark mass. However, deviation from the assumed $1/x$ behavior at low energies (allowed by theory and experiment) results in substantially different predictions on the parton luminosities at SSC energies. An assumed $1/x^{1.3}$ behavior for the input functions results in roughly a factor of five higher gluon-gluon luminosity at $\sqrt{s} = 5 - 10$ GeV. Steeper input will result in even greater increases -- up to a factor of 10 for input $1/x^{1.5}$ behavior. At the same $\sqrt{s}$, gluon-quark and quark-anti-quark luminosities are more sensitive to changes in small-x input than gluon-gluon luminosity. These results have a direct bearing on estimates of anticipated cross-sections for 'mini-jets' and b-meson production, among others, at SSC.

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Parton distribution functions (PDFs) are basic ingredients to prac-
tically all cross-section calculations for high energy processes at cur-
rent and future colliders. Our current knowledge on parton distributions
is based on: (i) experimental input on structure functions of deep inelas-
tic scattering processes, and (ii) QCD-based renormalization group equa-
tions which predicts the evolution of the distribution functions in the
variable q^2. Uncertainties on these PDFs result from: (a) lack of hard
experimental information on the behavior of structure functions below x ~
.05 , and (b) absence of knowledge on certain basic parameters of QCD,
such as the top quark mass M_t. About (a), practically all PDFs in actual
use make 'reasonable' assumptions about their small x behavior at current
energies, usually ~ 1/x for the gluon and the sea-quarks, and let the QCD
evolution equation do the rest. Concerning (b), they either neglect
effects due to the heavy quarks[1], or assume a conjectured value for M_t,
say 30 GeV.[2]

Since parton distributions rise rapidly at small x, and more so with
increasing Q (the relevant energy scale), predictions on important cross-
sections such as 'mini-jets' and B-meson production must be sensitive to
theoretical and phenomenological inputs to the PDFs for small x. On the
one hand, recent studies on the region of applicability of ordinary QCD
evolution equations has been reassuring for SSC energies[3,4,5]; on the
other hand, questions have been raised about the conventional assumed 1/x
behavior of input parton distributions at small x.[6,7] A number of consid-
erations suggest that a steeper x-dependence (for 'semi-hard' physics) is
not only theoretically possible, it may even be preferable.

With these considerations in mind, we have generated QCD-
renormalization-group evolved PDFs based on a number of different assump-
tions on the input small-x behavior and other QCD parameters. We then use
these PDFs to calculate parton luminosity functions and physical cross-
sections for comparison with the same quantities obtained with conven-
tional inputs. The results should give some indication as to the possible
range of uncertainties associated with such predictions. This short
report concerns only results on the parton luminosities. Further studies
of interesting cross-sections and refinements of the phenomenological
treatment will be reported later.

For this study, the parton distribution functions are generated by a
QCD-evolution program PDFIT using input distributions at Q = 2.5 GeV com-
puted from the Duke-Owens[1] and EHLQ[2] parametrizations in order to ensure

general agreement with existing data and to facilitate comparison with standard results.

To see the effect of the unknown top-quark mass on the evolution of the distributions, we computed PDFs using M_t = 30 - 150 GeV. The value of M_t determines the position of the top-quark mass threshold which affects the evolution of PDFs. Since the top-quark is only one of the six quarks, the effect due to this parameter is not expected to be large (except, of course, for the top-quark distribution itself not far from the threshold.) This is born out by the numerical calculation. Fig. 1 shows two sets of gluon-gluon luminocity curves for M_t = 30, 150 GeV, based on input parton distributions at Q = 2.5 GeV taken from Duke-Owens[1] set 1, and EHLQ[2] set 1 respectively. The differences due to the two different input top-quark masses is a few per cent; the differences between the two sets (Duke-Owens vs. EHLQ inputs) are slightly larger, but still not significant.

To study the impact on parton luminocities due to a modified behavior of the parton distribution functions at small x, we take the input distributions at Q = 2.5 GeV from one of the parametrizations, say EHLQ set 1; modify the power a in the $1/x^a$ prescription for small-x dependence of the gluon and sea distributions; and adjust the normalizations of the distributions such that all momentum and quark number sum rules remain to be satisfied. (The last point is necessary since the small-x region makes a substantial contribution to the sum rules, due to the steep rise of PDFs toward x = 0.) If the power a differs from the conventional value 1, it almost certainly is larger than 1.[6] The main reasons are: (i) the first-order renormalization kernel (Altarelli-Parisi) generates a 1/x dependence, even if one starts with a less singular one; (ii) higher order kernels most likely generate a small-x behavior more singular than $1/x$;[6,7] and (iii) the Q-evolution for moderate values of Q is quite unstable if a $\lesssim$ 1 (such behavior can easily lead to negative PDFs, hence cast doubt on the viability of the parton picture itself.)

More singular x distributions near x=0 put more partons in the small x region. The parton luminocities at small x will increase compared to previous estimates. The question is by how much. Fig. 2 shows the results of a calculation based on input gluon and sea distributions with a $1/x^{1.3}$ behavior, compared to those obtained with conventional input. Three sets of curves are shown: the gluon-gluon, gluon-u-quark, and gluon-b-quark luminocities, each for the two types of input small x behavior. We see that for small $\sqrt{s}$ (5 - 10 GeV) the gluon-gluon luminocity is increased by a factor of ~ 5, and those for quark-gluon by a somewhat larger factor. As $\sqrt{s}$ increases in value, the x-values involved in the luminocity calculation become larger, and the differences between the

results obtained with the two sets of inputs diminish. If we start with a even more singular distribution, say $1/x^{1.5}$ as suggested by ref.6, the differences at small $\sqrt{\hat{s}}$ will be bigger, as expected. The gluon-gluon luminocity, for instance, differs by a factor of more than 10 at $\sqrt{\hat{s}} = 5$ GeV from that obtained with conventional input..

Total cross-sections for various high-energy processes are proportional to the sum of all contributing parton-parton luminocity functions. The results reported here should give a good indication of the possible range of variation for predicted cross-sections which are sensitive to small-x partons. In particular, if the parton distribution functions are more singular at $x \sim 0$ than previously assumed, then we should expect a increase in the predicted cross-sections by a factor of 5 to 10 for semi-hard processes such as B-meson production and other mini-jet events.

References

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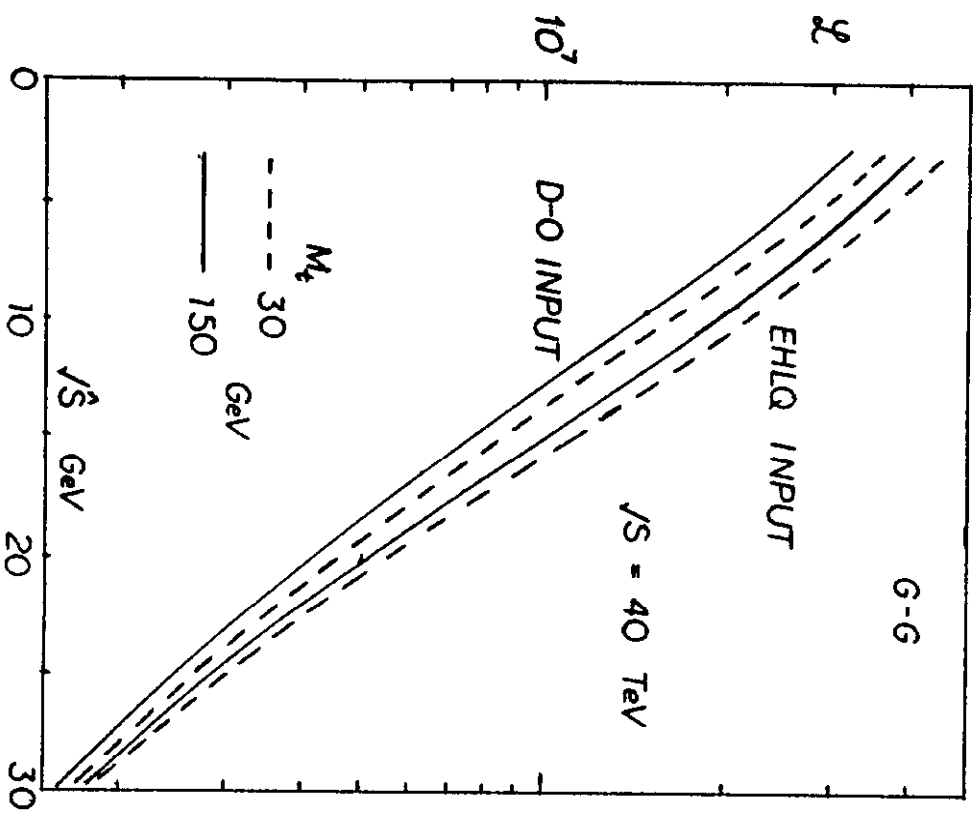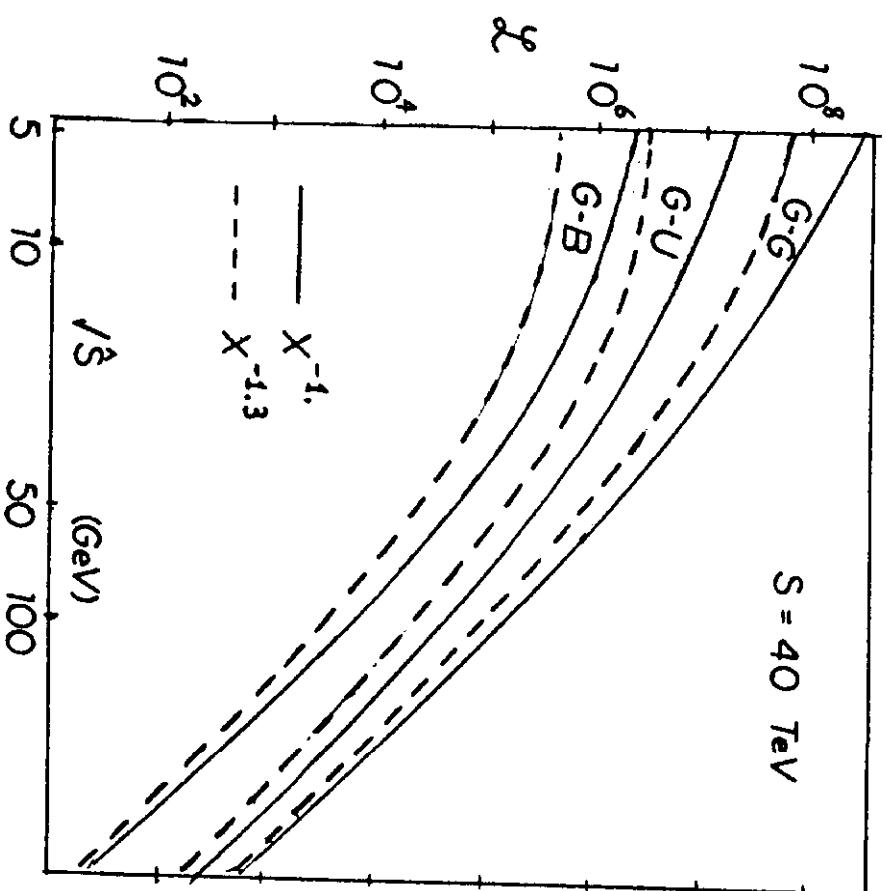
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FIG.1

G-G

D-O INPUT

EHLQ INPUT

$\sqrt{S}$ = 40 TeV

M_t

--- 30

—— 150 GeV

10^7

$\mathcal{L}$

$\sqrt{\hat{S}}$ GeV

0

10

20

30

FIG.2

S = 40 TeV

G-B

G-U

G-G

—— X^{-1}.

--- $X^{-1.3}$

10^8

10^6

10^4

10^2

$\mathcal{L}$

$\sqrt{\hat{S}}$ (GeV)

5

10

50

100